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Course in Descriptive Geometry and Stereotomy.

BY S. EDWARD WARREN, C.E.,

PROFESSOR OF DESCRIPTIVE GEOMETRY, ETC., IN THE MASS. INSTITUTE OF TECHNOLOGY, BOSTON. FORMERLY IN THE RENSSELAER POLYTECHNIC INSTITUTE, TROY.

The following works, published successively since 1860, have been well received by all the scientific and literary periodicals, and are in use in most of the Engineering and "Scientific Schools" of the country; and the elementary ones in many of the Higher Preparatory Schools.

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BY

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POLYTECHNIC INSTITUTE, AND AUTHOR OF A PROGRESSIVE SERIES OF WORKS
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PREFACE.

In geometrical, or mechanical drawing, exclusive reliance for accuracy may, in theory, be placed on good drawing instruments.

Practically, these instruments are not absolutely perfect as means to the ends to be accomplished by them, and from this, and momentary negligences of the draftsman, they are not infallible in accuracy of operation.

But, viewing the eye and hand simply as instruments for executing conceptions of form, they are incomparably more perfect and varied in their capacities in this respect than drafting instruments; and well directed practice should, and will, bring out this capacity.

Hence, other things being the same, he will be the most expert and elegant draftsman, whose eye is most reliable in its estimates of form and size, and whose free hand is most skilled in expressing these elements of figure.

Accordingly, in harmony with the law of easy gradations and connecting links which pervades nature, we find a special branch of free drawing which is peculiarly well adapted for a preliminary training of the eye and hand of the geometrical draftsman. This training consists simply in drawing various single and combined geometrical lines and figures, of various forms and sizes, by the unassisted hand; and constitutes a connecting link between ornamental free drawing and instrumental drawing.

These brief reflections have resulted from a recent inspection of a few simple pencil plates of such drawings forgotten for a long time, having been made by the writer several years since, in connection with the conduct of a short course of exercises of the kind above described.

As a further, and I hope not useless fruit of the foregoing views, the following little course is presented to all who, as draftsmen, may promise themselves benefit from the use of it, and for exercises of mingled interrogation and practice in schools.

By means of a love of skill and accuracy in the use of eye and hand, exercises like those of this volume may be made a pastime for the improving (especially if social) enlivenment of numerous odd moments, those times when *many subordinate excellencies can be acquired or perpetuated without interference with one's larger industries.*

My work may be thought deficient in the number and style of its illustrations; but it is meant to be supplemented by a free use of large plain lithographic, or other copies of ornamental devices; and of the blackboard.

Writing, as merely auxiliary to daily business, is not, in its intention, a branch of drawing. But, as an ornamental art, it is a species of free-hand drawing, not geometrical, however. Hence I have not treated of writing, while ample instructions on lettering have been deemed a due portion of the contents of this volume, since, moreover, the usual small size of letters makes their construction by hand alone more convenient than by the use of drafting instruments.

The good tendencies of accurate drawing in regard to mind and character are worthy of a closing notice, and indeed need hardly more. Practice in such drawing directly tends to make *close* and *accurate* observers, who will thus gain *distinct conceptions* of the objects of attention, and so of thought generally, and who will then pass on to *fidelity in the representation* of their observations and conceptions, and to growth in truthfulness of spirit.

It is proper to add that the theory of beauty of form as dependent, more on *angular* than on *linear* proportions, which is briefly recognized in this volume, is due to D. R. Hay, author of several ingenious and attractive works on geometric beauty.

The short chapter on the largely unwrought subject of geometric symbolism, may serve, in the absence of anything better, as the seed of richer and more abundant conceptions of beauty of thought linked to expressive forms.

NEWTON, Mass., ***January*****, 1873.**

CHAPTER I.

EXERCISES ON DIRECTIONS OF STRAIGHT LINES.

First Principles.

The direction of a line is its tendency towards a certain point.

The directions of two lines may be alike. The lines are then said to have the same direction, and are called *parallel.*

The drawing of *parallel lines*, or those whose *directions are alike*, is simpler than that of lines whose *directions are different*, and hence is here considered first.

A line which is "straight up and down," or perpendicular to the surface of water, like this, when the book is held upright, is called *vertical.* A *level* line is called *horizontal.*

The force of gravity acts vertically, hence objects rest with most stability in a vertical position on horizontal surfaces. Likewise, man himself, naturally stands upright, or *vertically*, and, generally, on surfaces whose lines are level, or horizontal. Hence vertical and horizontal are the simplest, most familiar, or primitive, directions of lines, and will be first considered.

Lines in space, not vertical or horizontal, are called *oblique.* Also lines lying in any flat surface, and not at right angles to each other are called oblique.

Before commencing the succeeding exercises, the learner should be provided with the following materials; and, throughout his progress should carefully follow the subjoined general directions.

MATERIALS.

For the practice of quite young pupils, where substantial accuracy, rather than fineness of execution is expected, quite cheap paper, or even a slate and pencil will answer.

For more advanced practice, heavy flat wove writing paper, Whatman's, or the German cartoon paper (drawing paper), may be employed, cut into plates of convenient size, as 7½ by 10 inches,—the dimensions afforded by paper of the "demy" size.

A common semi-circular "*protractor*," a semi-circular piece of thin material, divided into degrees on its curved edge.

A ruler 10 inches long and 1 inch wide.

Moderately soft pencils as Faber's No. 2, and 3.

Prepared india rubber, free from grit, of the best kind now known as "Artist's gum."

Spare pieces of paper, one, on which to rest the hand and so protect the drawing, and another on which to try the pencils. Also a strip for a measure of distances.

A fine file, on which the pencil can, by a rolling rubbing motion, be most neatly and readily sharpened to a round point.

When accuracy on a comparatively large scale is sought, as a training for bold sketching, large plates of coarse paper, and crayons, should be substituted for pencils, and small plates and figures. In fact, this may be done as a preliminary counterpoise to the somewhat cramping tendency of the mostly minute accuracy required in mechanical drawing. But for direct training in this accuracy, the pencils, and small plates, should be used as above indicated.

DIRECTIONS.

Depend on the unassisted eye and hand alone, from the beginning. They will, in due time, amply reward the reliance placed upon them. Ruler, Protractor, and Measure may be used to *test* the *straightness*, *direction* and *length* of lines already drawn, so that if incorrect they can be re-drawn. But they should never be used to locate, limit, or rule the lines; for thus no education is afforded to the eye and hand, only trifling skill is gained by them, and so the main object of the exercises is missed.

If a line is found incorrect, first consider carefully how it differs from what it was meant to be, then erase it, and study its direction well, and try again. *Excellent quality*, and not great quantity of drawing, is to be the chief object of ambition.

Avoid the use of the rubber by studying well the position and lengths of the lines *before* drawing them. *Mean* to have them appear in a certain way, and then make them so, as truly as possible; rather than hastily make a careless sketch and then seek how to correct it.

Be sure that a figure is as well done as possible at the time, in obedience to the preceding rules, before attempting a new figure.

Hold the pencil between the thumb and forefinger, and resting on the tip of the second finger. It can then be moved both with freedom and steadiness.

In drawing lines towards or from you, let the elbow be at some distance from the body. In drawing lines from side to side let the elbow be close to the body.

Arrange the seat and paper so as to look at the paper in a direction at right angles to it, without stooping, and let the desk be low enough not to interfere with the elbows.

Though all the lines of the following figures are horizontal, when the book lies flat, yet, for the sake of brevity, it may be understood that all those lines shall be *called vertical*, which are so when the book is held vertically. Lines from side to side may be *called horizontal*, and others, *oblique*.

Remember especially to sketch each of the figures, first in very faint lines, which can easily be erased if incorrect, before drawing the firm heavy lines of the finished figures. Do not, however creep along the line by short, disconnected, and hesitating steps, thus, ——‿———⌒———⌒—— but mark the line by a firm and unbroken movement, first lightly, thus, ———————————————— and then heavily, thus: ▬▬▬▬▬▬▬▬▬▬▬▬▬▬▬▬.

SINGLE LINES.

Example, 1. Draw *vertical* lines, beginning at *the top*, and far enough apart to prevent each from being a guide to the other, as a parallel. Thus let these lines be drawn at the middle and ends of the upper half of the plate.

Ex. 2. The same on the lower half of the plate, but beginning the lines at *the bottom*.

Ex. 3. Mark two points so as to be connected by a vertical line, and then draw a line joining them, beginning a little *above* the *upper point.*

Ex. 4. The same, but beginning *below* the *lower point.*

These, and all the examples, should be varied, by taking lines of various lengths.

Ex. 5. Draw horizontal lines, beginning at the left, and far apart, as at the top, middle and bottom of the left hand half of a plate.

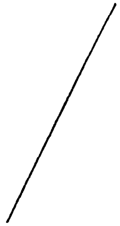
Ex. 6. The same on the right hand half of the plate, and beginning at the right. This will require special care.

Ex. 7. Mark two points so as to join them by a horizontal line, beginning to the left of the left hand one, and draw to the right.

Ex. 8. The same, only begin to the right of the right hand one.

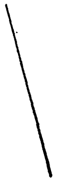
The foregoing constructions will divide the plate into quarters, in which the following may be drawn.

Ex. 9 to 12. May consist of the four preceding variations in the manner of drawing, applied to an oblique line, which inclines *from* the body and to the *right,* thus:

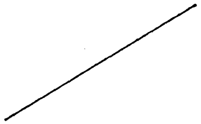


Ex. 13 to 16. May consist of four similar constructions of lines which incline *from* the body but to the left.

The last two examples should also be practised with the two following variations: First, let the lines be *more nearly vertical* than horizontal, thus:



Second, let them be *more nearly horizontal* than vertical, thus:



PARALLELS.

The following Examples permit so many variations in the order of construction, that each one, as numbered, must be generally understood to include several particular varieties.

Ex. 17. Draw *two* vertical parallels, first drawing the left hand one first; and second, the right hand one first. Also draw each, in the four ways described in Examples 1 to 4.

Ex. 18. Likewise draw *two* horizontal parallels, first, drawing the upper one first; and second, the lower one first, and each as in examples 5 to 8.

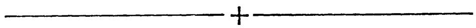
Ex. 19. Draw *several* vertical parallels, beginning alternately at top and bottom.

Ex. 20 to 22. May consist of similar variations in drawing two or more horizontal parallels.

Ex. 23 to 28. May consist of similar exercises on two or more oblique parallels situated as in examples 9 to 16, and including the variations in the amount of obliquity there pointed out.

OPPOSITE LINES.

These are lines starting at a given point; and proceeding in opposite directions, thus:



or towards each other from their outer extremities.

Ex. 29. Draw opposite lines, one upwards, and one downwards from the given point.

Ex. 30. Do., one to the right, and one to the left of a given point.

Ex. 31. Do., in the principal varieties of oblique position.

Ex. 32. Is a comprehensive one, consisting of the variation of the three preceding, by beginning to draw the opposite lines in each case from their outer extremities.

DOUBLE LINES.

All the preceding examples may be made in double lines; that is, lines as close together as they can be made without touching, and at first of the *same size*, and then, of *different* sizes.

Useful practice under this head consists in filling various figures, such as triangles, squares, polygons and circles, with parallel lines, which should be made equidistant by the eye.

General Example. Construct a series of examples of figures thus filled, each with one, two, three, or four sets of parallels, which will form an elegant imitation of bold line engraving.

CHAPTER II.

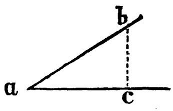
ELEMENTARY AND PRACTICAL EXERCISES ON RIGHT ANGLES.

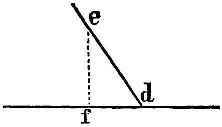
Principles.

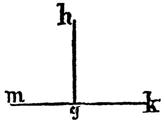
Beauty of form, considered as residing in certain geometrical properties of regular figures, results from certain proportions between their parts. These proportions may be regarded as arising from the *relative lengths* of the distinguishing *lines* of the objects; or from the *relative sizes* of their *angles.*

In moving, whether to walk, or to merely draw a line, we must begin each movement at a given point. The *direction* of our movement is first in our thoughts, rather than its *extent.* We first, if not oftenest, think, or ask, "*which way*" than "*how far.*" *Direction* is therefore a more primary idea than *length.* An *angle*, however, is merely difference between directions from a certain point. Hence *angular proportions*, or the proportion between the *angles* of a figure, are more elementary than *linear proportions*, or those between the *lengths of the lines* of the figure, and will be first considered.

In doing this it will be convenient to find first some angle as a *natural standard of comparison* for all others, and this we now proceed to do. When, then, two lines are so situated that, in moving on one of them, we do not at all move in the direction of the other, their directions are said to be *independent.*





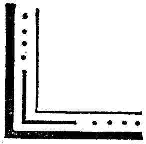


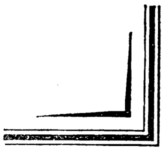
Thus, in these figures, by going from *a* to *b*, we also move as far as *ac in the direction* of the line *ac.* So by moving from *d* to *e* we go a distance equal to *df* in the direction of the line *df.* But, *when the two angles formed by the meeting lines are equal*, as at *mgh* and *kgh*, we do not, in moving to any distance on *gh*, move at all in the direction of *gm* or *gk.* Hence the directions of *gh* and *mk* are *independent*, and the angle included between them is the *natural* standard with which to compare all other angles. This angle between *independent directions* is called a *right angle;* and now some of the subsequent exercises are to consist in constructing, by the eye, various proportional parts of a right angle.

But, again, it follows from the explanation of vertical and horizontal directions, in Chapter I., that a right angle is in its simplest, most natural, or *standard position*, when its sides are in the *fundamental directions* of *vertical* and *horizontal.* We therefore begin with right angles in this position. Observe first, however, that we do not say perpendicular and horizontal, but *vertical* and horizontal, for a line in any position whatever, is perpendicular to another when it is at right angles with it, but there is but *one vertical*, or "straight up and down" direction.

EXAMPLES OF SINGLE LINES AT RIGHT ANGLES, WITH SIDES HORIZONTAL AND VERTICAL.

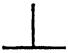
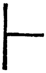
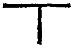
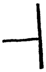
Ex. 33. Construct *one* right angle thus, └ and thus, ┘ and thus, ┌ and thus, ┐ making its sides from one to three inches in length, *each side ending at its intersection with the other.* Slight additions will give these simple elementary figures a pleasing character as designs for geometrical borders and corner pieces, thus:

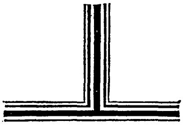


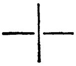


designs which it is easy to make evenly by observing the direction to pencil each line faintly at first, while locating it as intended.

Observing that the beauty of a border depends upon its *expressiveness*, as an echo of some characteristic of the work which it encloses, the first design would make an agreeable corner, for a plate of figures made up of points and straight lines. The second, with its swelled lines, suggests *strength* in the corner of the border, or *progression*, as in the shading, difficulty, or importance of the enclosed figures.

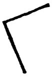
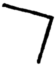
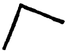
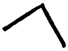
Ex. 34. Construct *two* right angles, by prolonging one of the sides beyond the vertex of the angle, thus,  and thus,  and thus,  and thus, 



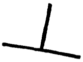
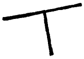
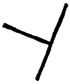
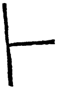
Ex. 35. Construct *four* right angles, by prolonging each side through its point of intersection with the other, thus 

RIGHT ANGLES WITH SIDES OBLIQUE.

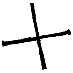
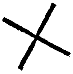
Ex. 36. Repeat Ex. 33 with the sides in various oblique positions, and of various lengths, thus:

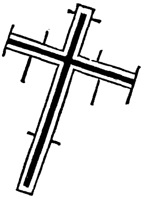





Ex. 37. In like manner, repeat Ex. 34, thus:

Ex. 38. Similarly, repeat Ex. 35, thus, but in each case make the lines from one to three or four inches long, from the point of intersection.

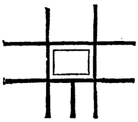


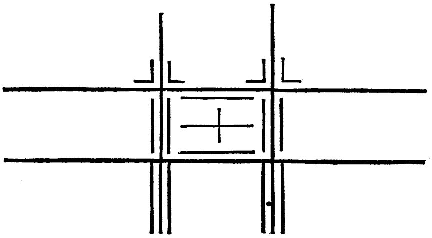
PAIRS OF PARALLELS AT RIGHT ANGLES.

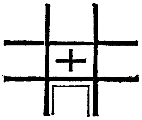
The Pairs Horizontal and Vertical.

Many variations can be made, and should be, in the order of drawing each of the following figures. Thus the vertical lines can both be begun at top or bottom, or one in each way; also, the horizontal lines may both be begun at the left end, or right end, or one in each way. Again, both of the vertical lines may be drawn first, or both of the horizontal ones, or one of each in succession.

Ex. 39. To give a more ornamental character to these simple elements, after seeking *truth* of representation, only, in the preceding elementary figures, they may consist in combinations of faint and heavy lines, as shown in a part of the following figures, all of which should be made of lines from a half inch to three or more inches long.

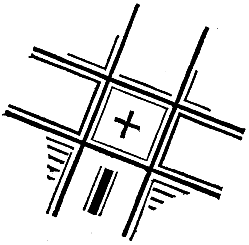


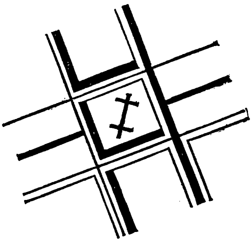




The pairs in oblique positions.

Ex. 40. Repeat Ex. 39, as follows:

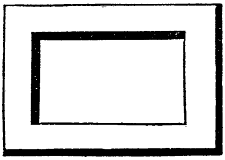


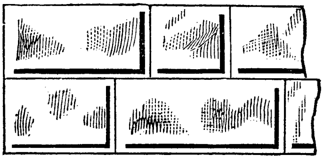


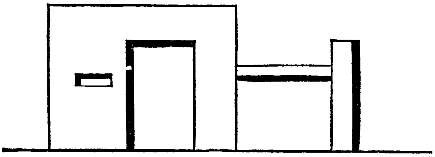
PRACTICAL EXAMPLES.

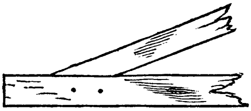
Ex. 41. The preceding elementary examples afford all the operations necessary in forming many simple drawings, either of geometrical designs for *surface ornament*, or of objects.

A specimen or two of each is added in this example.









The pupil is here again reminded always to make his figures very much larger than those of the book.

CHAPTER III.

DISTANCES, AND DIVISION OF STRAIGHT LINES.

Principles.

Having considered various *directions* of straight lines, we are prepared to estimate and represent *various distances* upon them.

Distances are *equal* or *unequal*. When unequal, we often wish to *compare* them. Distances may be compared, *first*, by taking one from the other, and thus finding their *difference*. This shows *how much* greater, or smaller, one distance is than the other.

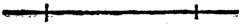
Distances may also be compared, *second*, by observing how many times one is contained in the other, and thus finding their *ratio*. This shows *how many times* greater the larger distance is than the smaller, or *what part* the smaller is of the greater.

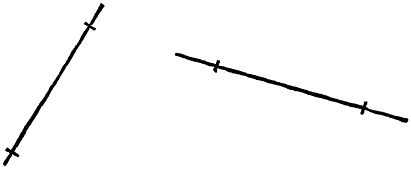
When we compare lines in this second way, we speak of them as *proportional*, or as *being in proportion* to each other, or as *having a certain proportion* to each other.

An indefinite line is one that has no given limits. In representing distances, we may either mark *a given distance* several successive times on an indefinite line; or, we may divide a given line into equal parts, and so *find* a series of equal distances.

EXERCISES IN MARKING OFF A GIVEN DISTANCE.

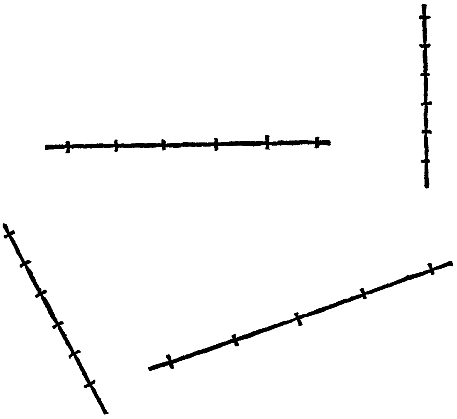
Ex. 42. Draw straight lines in different directions, and mark by the eye, the same distance, once, on all of them, thus:



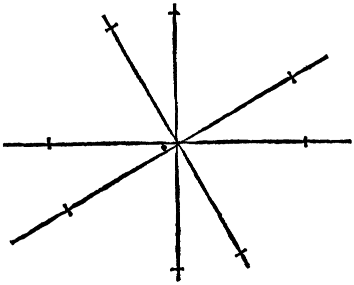


Transfer the distance on the first line to the edge of a slip of paper, and with this, as a measure, see if the distances on the other lines all agree with this measure. If not, observe whether they are too large or too small, and then, without making any mark on the paper before removing the measure, take away the measure, and correct the distances by the eye.

Ex. 43. In like manner, mark a given distance several times, on lines in various directions; thus:

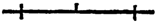


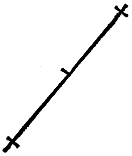
Ex. 44. Draw lines in several directions through the same point, and mark equal distances from the point on all of them; thus:



DIVISION OF LINES INTO EQUAL PARTS.

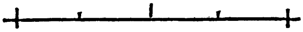
Ex. 45. Divide lines in various positions, as shown below, into two equal parts. This is done by marking the middle point of the line, and is called *bisecting* the line. Then apply the paper measure, and see if the two parts are equal. If they are not, the error found at the end of the line will be double the error in the required half. If three parts had been required, this final error would have been three times the error in the single third of the line, and so on. Then make the necessary corrections, accordingly.





To distinguish these figures from the preceding, mark only the *ends* of the line by dashes extending across the line.

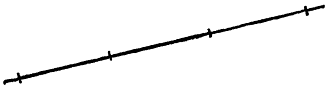
Ex. 46. Divide a line into four equal parts. To do this, bisect the whole line, and then bisect each of its halves.



In each of these exercises, let the given line be taken in various positions, though but one may be shown in the book.

In like manner, that is, by bisecting each quarter of a line, we should obtain eight equal parts, etc.

Ex. 47. To divide a line into three equal parts, that is, to *trisect* it. Estimate one-third of the line, and bisect the remainder.



To divide a line into nine equal parts, divide each of its thirds into three equal parts.

Ex. 48. In the preceding examples, we have divided each of the larger spaces into the same number of parts into which the whole was first divided.

Let a line now be divided into *six* equal parts, for example. Half of a line is more easily estimated than a third, hence divide the line first into halves. Also, having done this, one-third of a short distance, as the half line, is more easily estimated than a third of the longer whole line, hence divide each half into thirds, giving six equal parts in the whole line.

Ex. 49. To divide a line into any prime number, as five, seven, eleven, etc., of equal parts, it is necessary to estimate at once the fifth, seventh, eleventh, etc., part of the whole line. Yet this may be done more readily by dividing the line into two or more parts. Thus, one *third* of a line to be divided into *seven* equal parts would contain two and one third of those parts, and thus we could more easily estimate the size of one of those parts.

CHAPTER IV.

CIRCLES AND THEIR DIVISION.

Principles.

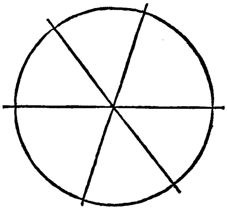
Direction is, as before said, tendency towards a certain point. A straight line has but one direction at all of its points.

A curve constantly changes its direction.

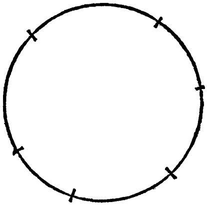
The simplest curve, and the one which will be the natural standard of comparison for all other curves, is the one which changes its direction at a uniform rate. The *circle* is such a curve, and all its points are at equal distances from one point within called its centre. The circle is, therefore, the simplest curve, and standard of comparison for other curves.

EXAMPLES. CIRCLES AND ARCS.

Ex. 50. To draw a circle. Sketch, faintly, several lines through a point, taken as the centre of the circle, and, from this point, mark off equal distances on each of these lines. Then through the points thus given draw the circle, thus:



Ex. 51. To draw the circle without drawing the lines through its centre. With the paper measure, mark a number of points all at the same distance from the centre, and then sketch the circle through those points.

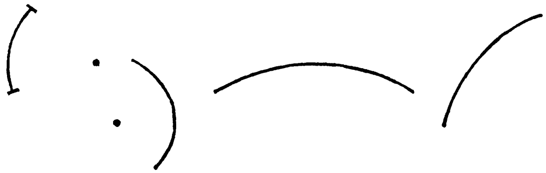


In both of these constructions, use fewer and fewer guides, and at last sketch a circle with no guiding point but its centre. Also practice often in rapidly drawing circles by hand on the black board.

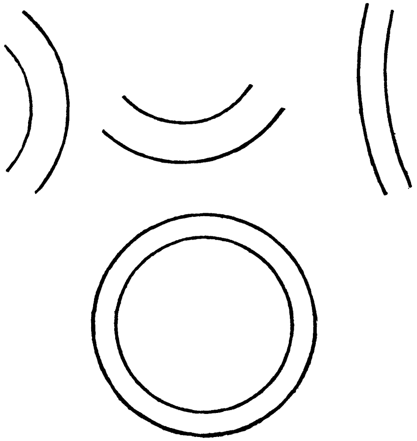
The distance from the centre to the circumference of a circle, is called its radius. The distance across the circle, through its centre is its diameter.

Parallel circles have the same centre, and are called *concentric.* A portion of the circumference of a circle, is called an arc.

Ex. 52. Draw circular arcs in various positions, and of various radii, and length, thus:



Ex. 53. Draw parallel arcs and circles, of various radii, and the former also of various lengths and in various positions, thus; and then *mark their centres.*

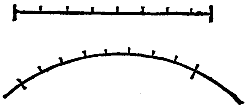


DIVISION OF CIRCLES.

Circles, or arcs, may, like straight lines, have given distances marked off upon them, and may be divided into equal parts.

The line which joins the extremities of an arc, is called the chord of that arc. When the arc is very short, its length cannot be ordinarily distinguished from that of its chord. It is on this principle that any given straight distance may be transferred to a circle or to any curve.

Ex. 54. To lay off a given distance on a circle or arc, divide that distance into a sufficient number of small equal parts, and then mark off on the circle, or arc, the same number of similar equal parts, thus, where the straight line is the given distance.



Ex. 55. Any diameter of a circle divides it into two equal parts, therefore draw several circles, and one diameter in each; but in different positions in the different circles, which may also be of various sizes.

Ex. 56. Two diameters at right angles to each other, divide a circle into four equal parts. Draw such diameters in various positions.

Ex. 57. The radius of a circle applies just six times to its circumference. Then lay off the radius once, on the circumference, as explained in Ex. 54, and then mark the other divisions, equal to the one thus obtained.

Ex. 58. Bisect each quarter circle in Ex. 56, which will give eight equal parts in the whole circle.

This bisection can then be continued to any extent, giving sixteenths, etc., of the circumference.

Ex. 59. Continue these exercises by trisecting the quarter circles, and bisecting and trisecting the sixth parts in Ex. 57, giving twelfths, eighteenths, etc., of the whole circle. Also make these divisions on circles of various sizes, and on arcs in various positions. The eye will thus be trained to estimate readily any given part of a circumference.

CHAPTER V.

PROPORTIONAL ANGLES.

Principles.

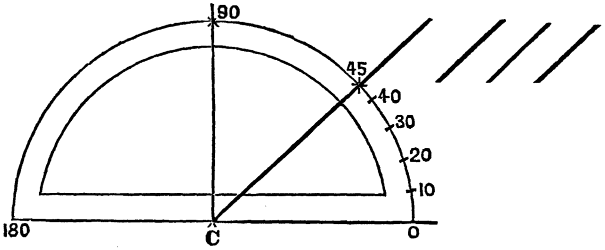
After acquiring power to draw lines, truly straight, in any direction, and to draw a true right angle in any position, much additional power of the eye to estimate, and of the hand to represent, will result from practice in estimating the values of the *angles* of objects. But we have seen that the right angle, upon which varied practice has now been had, is the natural standard of comparison for other angles. Hence the new group of valuable exercises which follow, is designed to train the learner in estimating and representing accurately any fractional part of a right angle in any position.

Every circle is considered as being divided into three hundred and sixty equal parts, called degrees and marked thus, 360°. Hence a half circle embraces 180°; a quarter circle, 90°; a sixth of a circle, 60°, etc. But, as already seen in the last chapter, two diameters at right angles to each other divide a circle into quarters; hence, as a right angle includes a quarter circle, or *arc* of 90°, between its sides, it is also called an *angle* of 90°.

In like manner, any angle is said to be an angle of as many degrees as there are in the arc between its sides, the centre of the arc being at the point or *vertex* of the angle. In other words an angle is said to be measured by the arc included between its sides. Hence the easiest way to divide an angle into equal parts, or parts having any given proportion to each other, is, to divide the arc between its sides in the manner required, and then to draw straight lines from these points of division to the vertex of the angle. The right angle being, as before explained, the natural angular measure for other angles, a right angle will be taken as the one to be variously divided, in the following examples.

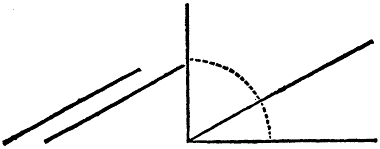
ELEMENTARY EXAMPLES.

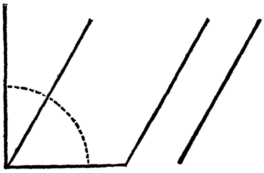
Ex. 60. Bisect a right angle, in each of the positions given in Ex. 33. To do this, sketch carefully a quarter circle between the sides of the angle and mark the middle point of this arc. Then join this middle point with the vertex of the angle as seen in the figure. To divide the angle into any other number of parts, divide the included quarter circle into the same number of parts. To test the angle thus estimated and drawn, use a "Protractor," as follows:



The protractor is a semi-circular instrument, whose semi-circular edge is divided into 180 degrees. A right angle is an angle of 90°. Half a right angle is 45°, hence if we place the straight side of the protractor on one side of the angle, and its centre, C, marked by a notch, at the point or *vertex*, C, of the right angle, as shown in the figure, then the required bisecting line C, 45°, will if correct pass through the 45° point on the divided edge of the protractor. If it fails to do so, then first carefully estimate, *by the eye*, the amount of error, and then erase the line and draw it over, remembering to *sketch it lightly*, till found correct. Having found the true direction of the required dividing line of the given angle, *draw a number of parallels* to it, in this, and all the following problems of divisions of angles.

Ex. 61. Construct a line which will cut off *one-third* of a right angle from either of its sides, thus:

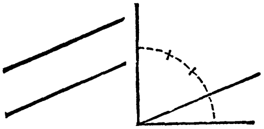
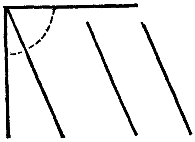




One-third of a right angle is 30°—measured by one-third of the quarter circle—hence in testing the lines after drawing them they should pass through the 30° point of the protractor in the first figure, and the 60° point in the second. In every case consider, as above, the number of degrees in the given fractional part of the right angle, and make the test accordingly.

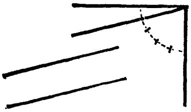
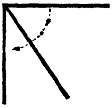
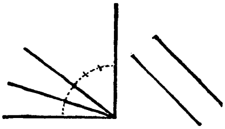
In the figure, only two parallels to the required direction are shown. The student should make many more, and in various positions around the original figure.

Ex. 62. Draw a line cutting off *one-fourth* of a right angle from either of its sides. This can be most accurately done by bisecting half a right angle, thus:

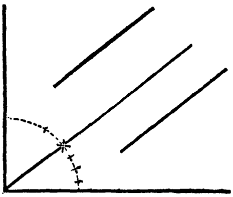
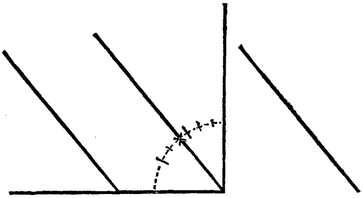



Observe, as indicated in these figures, to place the given right angle in any and all of the positions given in Ex. 33.

Ex. 63. Construct, successively, angles of *one-fifth*, and *two fifths* of a right angle; *i. e.*, angles of 18°, etc., thus:

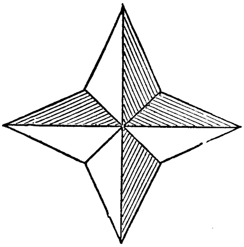
Ex. 64. Divide a right angle into two parts, one of 40° the other of 50°. This can be most easily done by finding one-third of the right angle, and making the angle and arc of 40°, one-third greater than the one of 30°, thus:

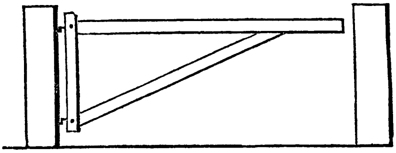
Ex. 65. Repeat the divisions of the right angle, given in the

preceding examples, upon right angles in various oblique positions as in Ex. 45.

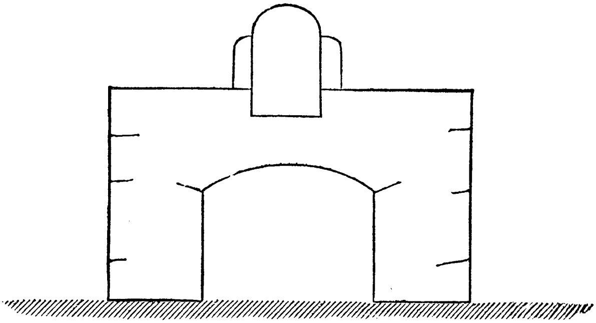
PRACTICAL EXAMPLES.



Ex. 66. A four pointed star, requiring two lines at right angles to each other, and the equal bisecting lines of those angles.



Ex. 67. A gate. Note that an angle of 24° is four-fifteenths of a right angle.



Ex. 68. An arch, giving practice in parallels, equal distances (each side of the arch, and the heights at the ends) and arcs, of various sizes, and parts of a circle.

CHAPTER VI.

PLANE FIGURES BOUNDED BY STRAIGHT LINES.

Principles.

A *plane figure* is a portion of a flat surface, bounded by lines. When bounded by straight lines, it is called a *polygon.*

Polygons are of various names, depending on their number of sides.

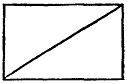
A Triangle has the least possible number of sides, viz., three. It has also three angles, and when one of these is a right angle, the triangle is called *right angled.*

A Quadrilateral, or quadrangle, has four sides, and angles. When both the angles and sides are equal, the figure is a *square,* and its angles are all equal. When the angles are right angles, but only the opposite sides are equal, the figure is called a rectangle.

A *Pentagon* is a figure of five sides. In a *regular* pentagon the sides and angles are all equal.

Likewise, a regular *Hexagon* has six equal sides and angles.

The diagonal of a four-sided figure joins its opposite corners, thus:



Figures of more than four sides, have more than one diagonal from any one corner.

The student is now prepared to sketch such simple objects as depend only on certain proportions between their angles.

According to the theory of beauty of angular proportions, briefly alluded to in Chapter II., those regular figures are most beautiful, in which the proportions of the angles can be expressed by fractions whose terms are small numbers.

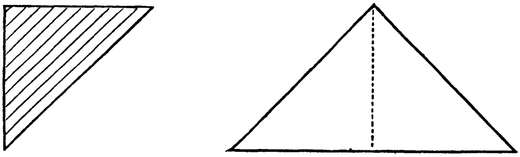
A great many familiar objects have sides of an oblong, that is a *rectangular* form, and these sides are divided by their diagonals into two equal right angled triangles. A triangle is the simplest plane figure, and *a right angled triangle is the simplest triangle, as a standard for the comparison of angular* *proportions*, since it contains a right angle, which is the natural measure with which to compare its other angles.

Rectangles, as floors, walls, doors, windows, the spaces between them, etc., are therefore, most beautifully proportioned, *when their diagonals divide their right angles into parts bearing* a simple proportion to each other and to a right angle.

Thus, if the diagonal of a rectangle divides one of its right angles into angles of 30° and 60°, the ratio of these is $\frac{1}{2}$, and their ratios to a right angle, are $\frac{1}{3}$ and $\frac{2}{3}$. These all being simple fractions, the rectangle will be found to have agreeable proportions.

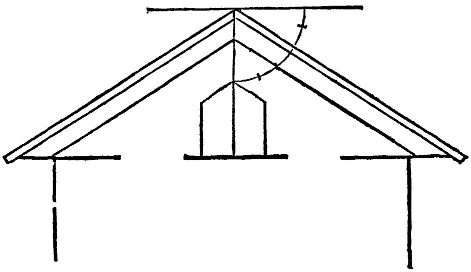
ELEMENTARY EXAMPLES.

The construction of regular figures, requires attention to the equality of some or all of the sides, as in Chapter III., as well as to their direction, and the proper size of their angles; and thus requires the application of examples in all the preceding chapters.



Ex. 69. A right angled triangle with equal acute angles of 45° each.

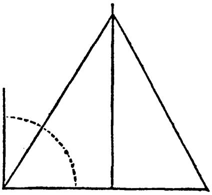
This triangle possesses the property of being divided by a perpendicular from its right angle to its opposite side, into two triangles of the same shape as the original whole. This property makes its construction easy. Draw this triangle in various positions, and fill it with lines parallel to its longest side, as above.



Ex. 70. A triangle each of whose halves is a right angled

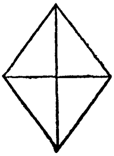
triangle with acute angles of 36° and 54°. Here $\frac{36°}{54°}=\frac{2}{3}$; $\frac{36°}{90°}=\frac{2}{5}$ and $\frac{54°}{90°}=\frac{3}{5}$. Also in the whole triangle $\frac{36°}{108°}=\frac{1}{3}$. These ratios being varied, while all of them are simple, the triangle is very pleasing and forms an agreeable end, or "pediment," to a roof, as seen in the figure.

Ex. 71 An equal sided triangle. This also, has equal angles of 60° each, and its halves therefore have acute angles of 30° and 60°. Draw several such triangles, and fill each one of some of them with one or more sets of lines, parallel, or perpendicular, to some one of its sides.



Ex. 72. Construct squares of various sizes and in various positions, first without their diagonals and then with them.

Ex. 73. A figure of four equal sides, but whose opposite angles, only, are equal, is called a Rhombus, thus:

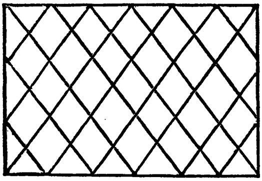


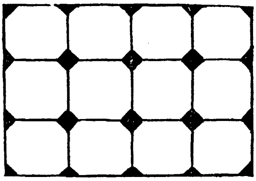
This figure is most easily constructed by first drawing its diagonals so that each shall be at right angles to the other at its middle point, and by then joining their extremities.

Let rhombuses of various proportions be drawn.

A square may also be drawn by its diagonals in the same way.

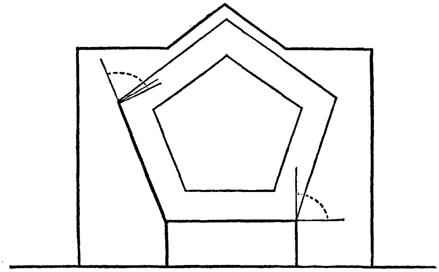
Ex. 74. After the practice thus far had, various designs in plane figures can be executed, such as the following. These

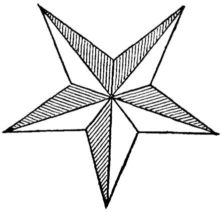




examples obviously require the divisions of lines into equal parts. Also, in the second figure, the marking of equal distances, viz., the semi-diagonals of the little squares.

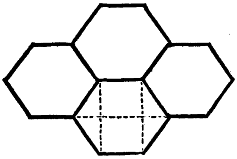
Ex. 75. Embraces a regular pentagon and some applications of it.



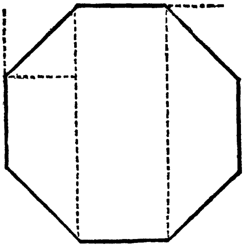


The external angles of a pentagon formed by producing or extending its sides, are each equal to 72°, or four-fifths of a right angle, and are constructed accordingly. The five pointed star is most agreeably proportioned, by joining the alternate points in order to obtain the direction of the sides of the star points. Also, the middle line of any point, when extended, becomes the dividing line between the two opposite points.

Ex. 76. Hexagons. These polygons have angles of 120° at their corners. They can therefore be combined as in pavements, so as to completely fill a given space. It will assist in constructing this figure, to remember that each of its sides is equal to the distance from its corners to its centre. Observe, also, that the longer diagonal is divided into four equal parts by the shorter ones, perpendicular to it, and the centre.

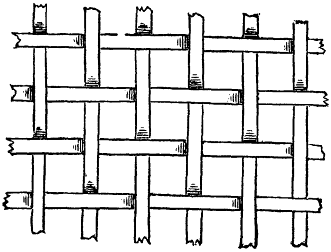


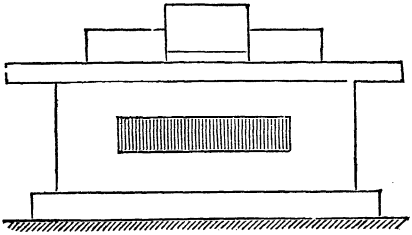
Ex. 77. Divide a circle into eight equal parts, by diameters at 45° with each other, and join the points of division by straight lines, which will give a regular *octagon*, or eight sided figure. This figure can also be drawn, by considering that its external angles are each equal to 45°, thus:



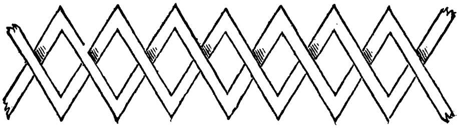
PRACTICAL EXAMPLES.

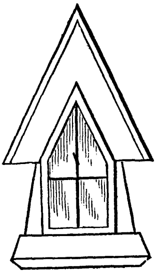
Ex. 78. Wholly made up of vertical and horizontal lines.

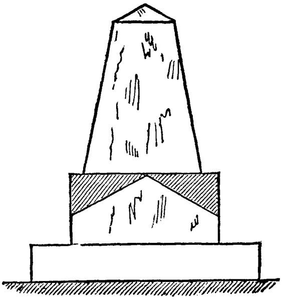




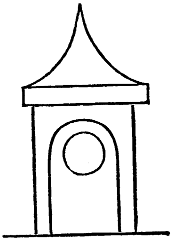
Ex. 79. Embraces oblique lines.

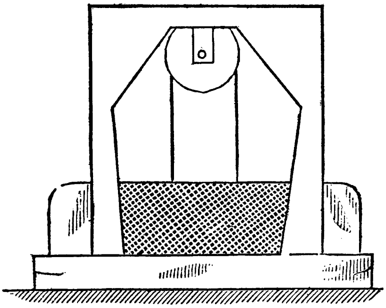


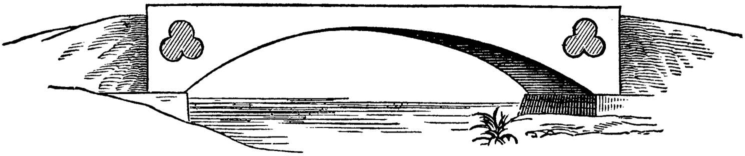




Ex. 80. Embraces circular lines.







The figures of interlacing lines are best made by sketching the whole in *very faint*, and *unbroken* lines, at first; after which those portions of each line, which are meant to be visible, can be retraced in firm and heavy strokes.

CHAPTER VII.

CURVES AND CURVED OBJECTS IN GENERAL.

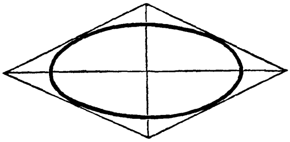
We have thus far considered only circular curves. These, however, are only the simplest among an endless diversity of curves, many of which are of great beauty, as well as common usefulness.

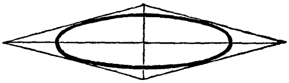
When any curve and straight line merely touch at one point, they are said to be tangent to each other, and just at the point of touch, or *tangency*, *they lie in the same direction.* Hence *any curve can be much more easily sketched*, *if we know several tangents to it at different points.*

A circle can evidently be placed, or "*inscribed*" in a square, so as to be tangent to it at the middle point of each side. A curve similarly inscribed in a rectangle is called an *ellipse.* Now observe that as all squares are of the same shape, though of different sizes, so all circles must be of the same shape, also. But there is an endless variety in the proportions of different rectangles, and hence there may be an equal variety of ellipses.

A right angle being more easily estimated than other angles, *it is also a special help*, *in sketching a curve*, *to have one or more lines which the curve must cross at right angles.* Hence it will be easier to sketch an ellipse in a rhombus than in a rectangle; for in the former, the ellipse will be tangent to the four sides, and will cross each diagonal, at right angles with it, and at equal distances from its extremities.

Ex. 81. Sketch ellipses of various proportions by the rhomboidal method, thus:



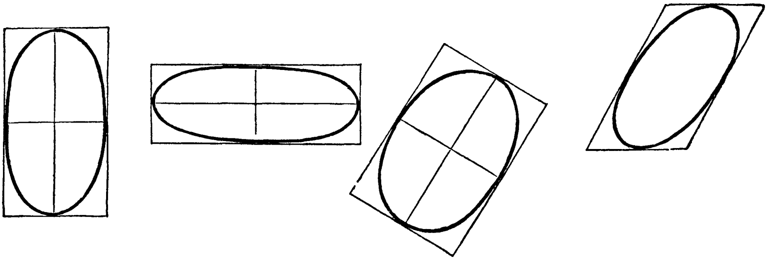


We may mark the *middle point of each side*, as the points of tangency of the ellipse, the sketching of which will then be quite easy.

Let this exercise be continued, in the sketching of ellipses in rhombuses placed in various oblique positions, and, also, with their longer diagonals placed vertically.

When an ellipse is inscribed in a rectangle, it crosses the centre lines of the rectangle at right angles, at the points of tangency with the sides of the rectangle. Thus the eight guiding positions afforded by the rhombus, are reduced by union to four, in the rectangle. The ellipse will, however, cross the diagonals of a rectangle at equal distances from its corners, but not in a perpendicular direction.

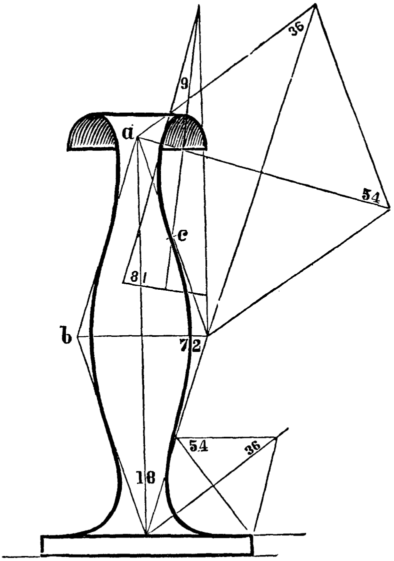
Ex. 82. Sketch ellipses in rectangles and other figures, of various proportions and positions, thus:



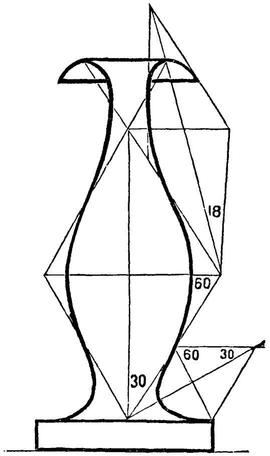
An ellipse is a curve of most delicate grace, and should therefore be most faithfully studied and carefully drawn. The most offensive error in shaping it, is, to represent it as pointed at the narrow end, which it is not, in the least.

By combining elliptical arcs of various proportions, tangent to each other, various graceful forms adapted to ornaments, such as vases, may be composed. In doing this the relative proportions of the ellipses should not be chosen at random, but so that the angles of their enclosing rhombuses should form simple ratios. Moreover, these rhombuses should be in simple relative positions, and the corresponding angles in the different ones should form simple ratios.

Ex. 83. In this design for a vase, all the angles, some of whose degrees are given in the enclosed numbers, are 9°, the *square* of 9°, or *even multiples* of 9°. Also at the base, two rhombuses have a common vertex; and at top, two have a side and two vertices in common. The acute rim-rhombus has its sides perpendicular to *a* 54 and *b* 72, its right side passes through the corner 72, and its diagonal passes through *c*, the junction of two arcs, and centre of *a* 72. Moreover, the diagonal 72–36 coincides with 18–72 produced, and the side 72–54 is parallel to the diagonal 18–36.



These mostly very simple relations of the rhombuses, and their angles, yield a very pleasing form, each side of which embraces four different elliptical arcs, of which the one running upward from *c* terminates on *a* 54.

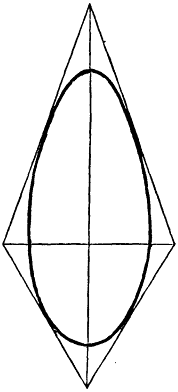


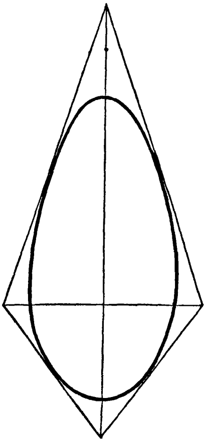
Ex. 84. In this design, the relations are in part, more, and in part less simple than in the preceding, and the result will hardly be thought more agreeable than before.

The principal, and the base rhombuses are of the same proportions, as seen by their angles, and therefore enclose similar ellipses, which gives less decided variety in the outline at the base. The upper side-rhombus, with its angle of 18°, side of one in the central rhombus of 60°, gives the comparatively complex and unfamiliar ratio $\frac{3}{10}$. Also its right hand corner is arbitrarily located on a horizontal line through the upper vertex of the central rhombus.

In both of these designs the rolling rim might be omitted by terminating the sides of the vases on the longer diagonals of the narrow upper side rectangles.

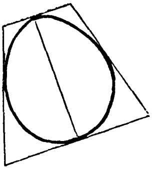
Ex. 85. By substituting for a rhombus, two dissimilar half rhombuses, having a diagonal in common, the beautiful egg-shaped curve will be formed, thus:

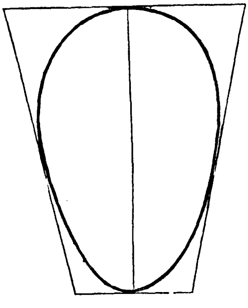




In the first of these figures, the acute half angles are 20° and 30°, whose ratio is therefore $\frac{2}{3}$. In the second figure the corresponding angles are 18° and 36°, having therefore a ratio of $\frac{1}{2}$, and affording a more decidedly egg-shaped curve.

Ex. 86. An egg-shaped oval may also be inscribed in a regular trapezoid, that is a figure having two unequal but parallel sides, both of which are bisected by the same line, perpendicular to both, thus:

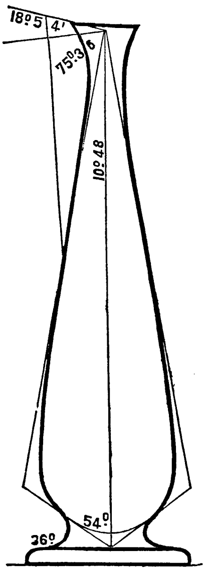




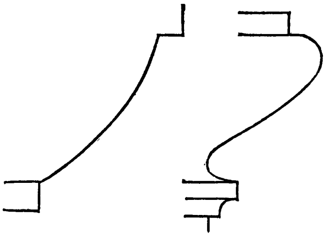
Let these ovals be drawn in a great variety of proportions and positions, both in rhombus-like figures and trapezoids, *and with as frequent reference as possible to leaves,* which exhibit a great variety of graceful ovals.

Ex. 87. The material of vases, etc., being originally plastic, it may be supposed to settle by its own weight into oval forms before hardening. For this reason, as well as from the greater stability associated with breadth at base, egg forms are more admired in pottery articles than true ellipses. The annexed design illustrates these remarks. Its angles of 36° and 54°; 54° and 10°–48′ (ten degrees and forty-eight minutes) 75°–36′ and 18°–54′, give the simple ratios $\frac{2}{3}$, $\frac{1}{5}$, $\frac{1}{7}$, $\frac{1}{4}$.

The student should make a variety of similar designs.

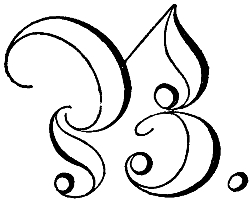


Ex. 88. On account of the pleasing associations of stability and decision with horizontal and vertical lines, as indicated in Chap. I., a curve which enters into the composition of any solid and fixed object is most pleasing when it has one or more horizontal or vertical tangents.

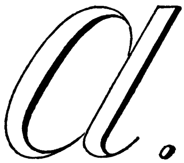


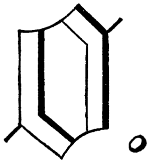
Thus, there is more vigor, as well as variety, in the curve in the second of these figures, than in the first.

Ex. 89. As we here propose only such exercises as are more closely associated with geometrical drawing, we only allude to



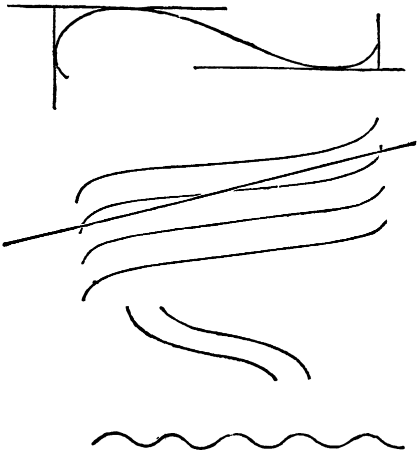
the careful drawing of German text and common writing (script) letters on a large scale, as an excellent exercise in the close study and varied practice of drawing curves.





The German text, and all upright letters should be evenly balanced on each side of an imaginary vertical centre line, in order to give them the most satisfactory appearance.

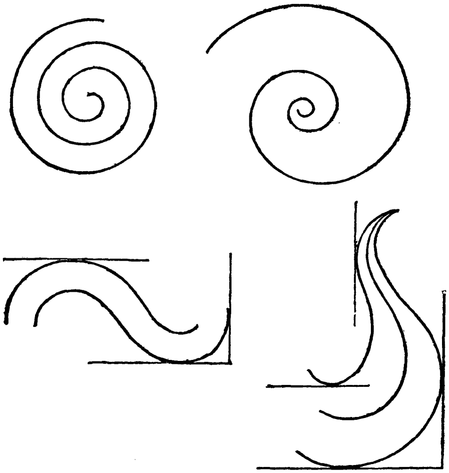
Ex. 90. The varieties of curves being innumerable, a few are here annexed by way of suggestion. The student can devise many others.



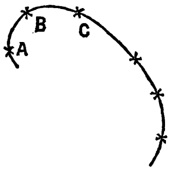
The group of four parallel curves affords an excellent example for practice, each curve being nearly straight in the middle, and sharply curved at the ends, while its left-hand half is convex upwards, and its right-hand half equally so downwards; and each with a vertical tangent at its extremities.

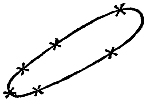
Of the two spirals, it will be seen that one increases its radius uniformly, giving equal radial distances between its successive turns, while the other expands at an increasing rate.

The use of tangents in sketching curves is also illustrated in these examples.

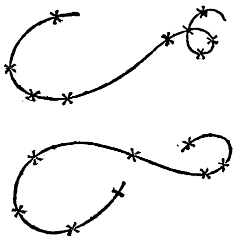


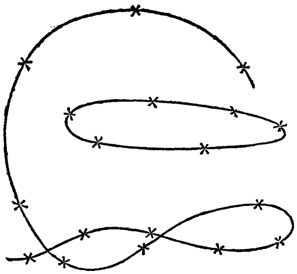
Ex. 91. *An exercise of peculiar utility*, is found in sketching easy curves through several given scattered points. This operation frequently occurs in geometrical drawing, when other than circular curves are to be described. The essential things to be observed in these cases, are, *first*, to avoid all sudden, irregular, and unnecessary variations in the rate or degree of curvature, and, *second*, especially to avoid making an angle at any point in the intended curve. These important requirements can be met by keeping at least *three* successive points in view at once,





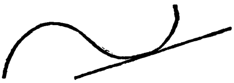
Thus, while joining A and B in the figure, keep C in view, and operate likewise in making all the figures.

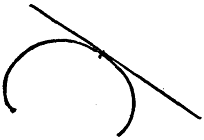




The student should practice extensively on this example, *first taking the points*, in many different relative positions, and then running easily flowing curves through them.

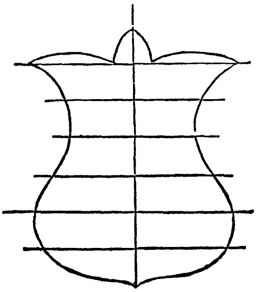
Ex. 92. In several of the preceding examples, curves have been drawn tangent to straight lines previously drawn. We here add an example of drawing tangent to curves already drawn.

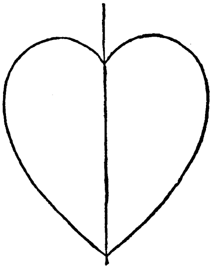


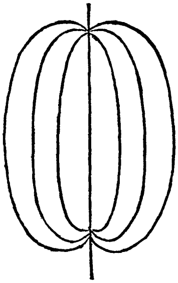


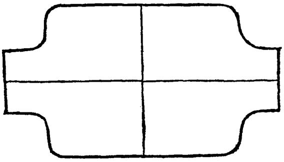
The tangent may be drawn through a given point out of the curve, as in the first figure, or through a given point on the curve as in the second figure.

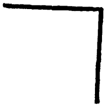
Ex. 93. Finally, the examples of this chapter close with practice in the very nice operation of drawing symmetrical figures with variously curved outlines. By symmetrical figures, are meant those which are divided by a centre line into two exactly similar halves, as in this figure. The difficulty in such figures, after forming one side in a pleasing curve, is, to make the other side of exactly the same form but in a reversed position. This can be done, as in the figure, by drawing lines perpendicular to the centre line, and by marking on them equal distances on each side of the centre line. The following are other examples of symmetrical figures, some of which have two centre lines. The learner can devise many other figures of similar character.











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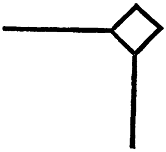

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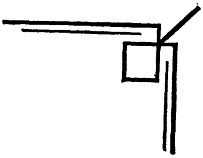

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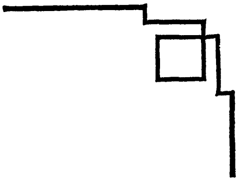

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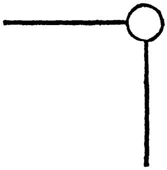

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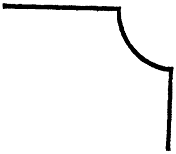

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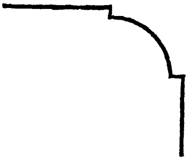

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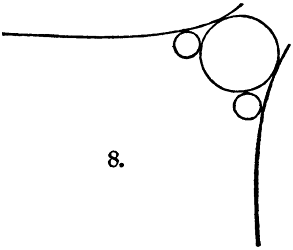

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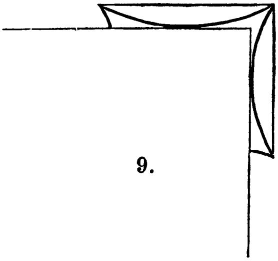

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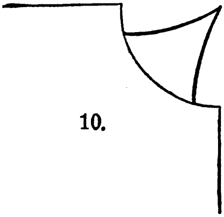

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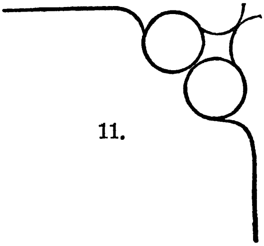

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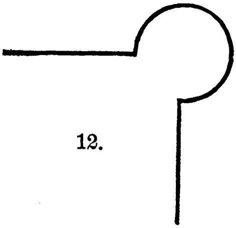


12.

Ex. 94. Representing a few elementary corner pieces, illustrates some of the foregoing principles. 10 is inferior to 9 because its main spur seems weakly placed, or driven in, while the spurred corner, 9, is firmly planted. 7 is better than 6, because it cuts out less of the interior, and because the grace of the curve is protected by the strength of the square corners at each side of it.

Thus the *skeleton* of every corner should embody a *good idea*, for no richness of detail in ornament can redeem bad governing outlines.

Attention to such simple principles as these will guide in the design or selection of borders, and prevent the necessity of presenting an elaborate collection of them here, when they can be seen in such abundance in type founders' collections, and in engravers' and printers' works, together with various ornamental devices.

Another principle, disregard of which through disproportionate interest in some trivial thing, has spoiled many a drawing, is this. Ornamental devices on drawings of solid worth, should never represent any thing essentially mean, or rudely comic, or even a reminiscence of anything, which however pleasant, is of transient interest. Such things as the latter, when preserved at all, should be in a separate form. In fact, sense of humor is best delighted, and the happiest laughter excited, by the simple sight of a beautiful border, or other work, some simple quality of which, such as its compact neatness, or clean firmness, is highly suggestive of analogous attributes in its maker.

CHAPTER VIII.

LETTERING.

General Principles.

Lettering, though not strictly a part of a drawing, is a necessary appendage to it, it being generally indispensable to the full understanding and intended use of the drawing. And as, also, there should be uniformity of accuracy and elegance in all parts of the draftsman's work, lettering is properly included among the fundamental operations, which he should be familiar with before applying his art in practical cases.

Besides, although geometrical drawings should be principally titled with geometrical letters, yet these letters are, on account of their usually moderate size, as well as variety and curvature of outline, most conveniently made by the free hand. Hence the draftsman's training in lettering appropriately falls among the subjects of free geometrical drawing.

Two points should be constantly remembered during the practice of lettering: *first*, *uniformity* of size and proportions, and, *second*, beauty and regularity of form in each letter. Ill-shaped letters, if of uniform size, proportions, and distance apart, and truly ranged in a straight line or regular curve, will look tolerably neat. Elegant letters will, on the other hand, appear badly, if irregularly sized and located. Both uniformity, and elegance are, therefore, indispensable to perfect lettering.

The learner's previous practice, in marking equal and proportional distances and angles, should enable him to secure uniformity in his letters; and his practice on curved and other irregular lines and figures, should enable him to give them elegance of form.

All the letters described in this chapter should first be drawn on plates of smooth heavy brown paper, about 11 by 14 inches in size, and with a crayon or soft pencil. They should be made three or four inches high, so as to afford exercise in free and broad movements of the hand, and may afterwards be made of ordinary sizes, on smaller plates, and in title pages.

ROMAN CAPITALS.

Before entering upon a general discussion of all the varieties of letters, we will make a special study of the common Roman capital letter, which is a sort of standard which all other letters are made to resemble, more or less closely, in certain particulars; and from which, as a starting point, variations are made in designing fanciful letters.

Plate I. *The Alphabet in Large Roman Capitals.*—This alphabet is arranged in three groups, so as to form progressive exercises in the drawing of the letters. The first group embraces those letters such as I and H, etc., which are composed, wholly or mostly, of *horizontal* and *vertical straight lines.* The second group contains all those letters in which *oblique straight lines* are prominent; while the third group embraces those letters which are largely made up of *curved lines.*

Letters, as large as those of this plate, may be made by instruments, by observing certain proportions in their form; but, inasmuch as, in common practice, letters are of such size that they are more conveniently made by hand, it will be far better for the student to make the large letters of Pl. I. by hand, at least so far as to sketch their curved lines, and the points through which their straight lines pass; after which, the lines, if inked, may be ruled. A running commentary on the different letters of Pl. I. will now be sufficient. I, the simplest of all the letters, consists of a vertical column, whose width may properly be made equal to a quarter of its entire height. The caps at the top and bottom project beyond the column a distance on each side, equal to half the width of the column. These proportions may be observed in the wide parts and caps of all the letters.

We thus have for an I the following complete proportions: Divide its height into sixteen equal parts. Then its height = $\frac{16}{16}$, its total width $\frac{8}{16}$, width of column $\frac{4}{16}$, projection of cap $\frac{2}{16}$, and thickness of cap $\frac{1}{16}$. These dimensions are to be preserved in the vertical columns of all the letters. Also all wide columns are to be of $\frac{4}{16}$ *perpendicular* width, and all the caps are to be $\frac{1}{16}$ thick.

Having thus fixed upon a proper thickness for the caps, let lines be ruled parallel to the extreme top and bottom lines, to aid in making these caps of uniform thickness on all the letters

Each column of the H is like an I. The extreme width of this letter allowing $\frac{1}{16}$ between the caps is equal to $\frac{17}{16}$ of its total height.

The height of the arm of the L is $\frac{7}{16}$ of the total height of the letter. The extreme width of this letter, and of F, making the arms $\frac{1}{16}$ longer than they are high, is $\frac{14}{16}$ of the height. The ends of the arms must be $\frac{1}{16}$ thick. F is like an L turned upside down, with the addition of the middle arm, whose height is half the height of the letter, and whose right-hand line is midway between the right-hand line of the column and the extreme right-hand line of the letter. E differs from F only in having another arm. Some designers make this letter a little wider ($\frac{14}{16}$) at bottom than at the top, and also make the height of the top arm a little less than that of the lower one. This method gives variety and an appearance of stability.

T, having an arm on each side of a central column, has its extreme width equal $\frac{18}{16}$ of its total height. Notice, on all these arms, that their curved sides are nearly quarter circles, giving solidity of appearance to the arms. None of these arms should be short, thin, or pointed.

Passing the hyphen we come to letters having oblique elements. V having its *average* width only equal to half its extreme width, since it comes nearly to a point at one extremity, may be made of extra width at the top; thus, let the total width be such as would be given by two wide columns with $\frac{1\frac{1}{2}}{16}$ between their caps. This width will then be $\frac{18\frac{1}{2}}{16}$ of the whole height. Let the perpendicular width of all narrow columns be $\frac{1}{16}$, and the horizontal width of V and A at their points $\frac{1\frac{1}{2}}{16}$.

Observe, that the left hand column is the wide one, and that in all letters having slanting columns, except Z, the heavy column slants *downward* towards the *right.* Similar general directions to the preceding, apply to A. The cross bar of this letter may be half way from the bottom line to the inner angle. In K the under side of the narrow arm may intersect the vertical column, a little below the middle, as at two-fifths of its height, so that the wide oblique column may not intersect the vertical column. The extreme width at the top equals the total height, and at the bottom equals $\frac{17\frac{1}{2}}{16}$ of the whole height.

N, having an oblique wide column, but being a square letter, having two vertical columns, does not need the extra width given to V and A. The length of full caps to oblique wide columns being $\frac{8\frac{1}{2}}{16}$, and to vertical narrow ones $\frac{5}{16}$, the total width at top, allowing $\frac{1}{16}$ between caps, if there were a full cap at the left upper corner, will be $\frac{14\frac{1}{2}}{16}$. There is no cap at the lower right-hand corner.

The under edge of its wide column is drawn from the left side of the foot of the right-hand narrow column, tangent to the slight curve which connects the upper left-hand cap with the left-hand narrow column. M has its total width equal to $\frac{21}{16}$ of its total height. The point of the V-shaped part is on the bottom line, and midway between the inner lines of the adjacent vertical columns. W, the widest letter of the alphabet, is of an extreme width equal to $\frac{27\frac{1}{2}}{16}$ of its extreme height. Its oblique lines are parallel to the corresponding lines of V. The extreme width of Z is equal to $\frac{14\frac{1}{2}}{16}$ of the height. Its arms are lengthened, as there are no caps opposite to them. The lower one is $\frac{10}{16}$ long and $\frac{8}{16}$ high, the upper $\frac{9}{16}$ long and $\frac{7}{16}$ high.

The left-hand vertical lines of the left-hand caps of X are in a vertical line. Reckoning from these lines, the extreme width at bottom is equal to $\frac{15\frac{1}{2}}{16}$ of the total height, and at top it is equal to $\frac{14}{16}$ of the height. In Y the outer oblique lines intersect the vertical column a little below the middle, as at a distance equal to the thickness of the caps. The whole width at the top equals $\frac{17}{16}$ of the whole height.

Passing the second hyphen, we come now to letters in which curves form a prominent part. The total width of J is $\frac{11}{16}$ of its height. Its larger curve, convex downward, has for a chord a horizontal line, at a height above the bottom equal to $\frac{5\frac{1}{2}}{16}$ of the height. The extreme width of U is $\frac{14}{16}$, of D $\frac{16}{16}$, of P $\frac{15}{16}$, and B $\frac{15}{16}$, of the height. The bow of the P should intersect the column a little below the middle, while the upper bow of the B may properly intersect the column a little above the middle, making the lower bow project $\frac{1}{16}$ beyond the upper one. R is $\frac{16}{16}$ wide at bottom. It differs from B so little, as not to need further description. By omitting the tail of the Q it becomes an O. The greatest width of the tail equals that of a wide column, and it extends three-fourths of the same width below the body of the letter. In either case the extreme width equals $\frac{14}{16}$ of the height. The extreme width of C equals $\frac{15}{16}$. The highest and lowest points of its outer curve are in the middle of the extreme width; and the corresponding points of the inner curve are half way between the inner point of the lower curved arm and the vertical tangent to the inner curve. In a letter as large as this, it is well to let the upper arm set back, a distance equal to the thicknes of a cap, so as to prevent the overhanging look that it otherwise would have. The extreme width of G equals its total height. Its construction is evident from the figure, after the description of C, that has been given. The whole width of S equals that of Q, and its arms are nearly like those of C. Some designers make the lower half higher and wider than the upper half, but as S is, to a beginner, the most troublesome letter, it is here given in its simplest form. To sketch it readily, it is only necessary to keep in mind that the outer curve at the top becomes the inner one in the lower half, and so must be carried below the middle of the letter and curved sharply to form the inner line of the lower half. & is less subject to rule than the proper letters of the alphabet. The design on Pl. I. is offered as being more pleasing than that in which the wing over the period ends in a rectangular cap. The dotted lines show a modification of the design, ending in a large circle.

The proportions here given are not absolute, but only relative. Thus an ordinary letter, as an H, or an E, may be made twice as wide as it is high, or half as wide as it is high, but in that case all the other letters would have similar modifications of their present proportions. Such letters are called, respectively, *expanded* and *condensed* letters.

Directions, much more minute than the preceding, are sometimes given for lettering, but, after affording a few essential hints concerning the general proportions of letters, it is here preferred to leave the details of their design to the taste and judgment of the designer.

LETTERS IN GENERAL.

In examining a type-founder's specimen book, one may imagine, from the exceeding variety of letters therein exhibited, that it must be impossible to reduce them to any system. But a closer examination will reveal a few comprehensive features, according to which all letters may be readily classified in groups.

By acquaintance with the distinguishing characters of these groups, and their modes of variation from one another, it will be easy to design uniform letters in any proposed form or style, which is much better than a mere copying of them, without ability to proceed independently of a copy.

All letters may be included in two grand divisions.

I.—*Geometrical letters* are all those which have a definite geometrical outline, which could be made with drawing instruments; and

II.—*Free-hand letters*, or those of so irregularly varied outline that they must be made by hand only, guided mainly by the fancy of the designer.

Since the letters called geometrical are the ones mainly used in geometrical drawing, they will chiefly be noticed in this section. The student, by collecting a number of hand-bills, programmes, business cards, sheet-music covers, etc., will have materials for a valuable scrap-book of letters, which may be arranged according to the classifications presently to be given, and which will be useful for reference, and will contain numerous practical illustrations of the explanations which follow.

By examining such a collection, it will be seen that in all ordinary letters three things may be distinguished—

(*a*) the *essential elements*.

(*b*) the *complementary additions*.

(*c*) the *decorations*.

By the *essential elements* of letters, are meant those portions which are necessary, and sufficient, to enable one to recognize those letters. The first half of each of the first two rows of Pl. II. are letters formed of essential elements only.

By *complementary additions*, are meant the caps, and the hanging parts of the arms, etc. The letters of the first four rows of Pl. II. are, with the exception of those just mentioned, letters having these additions.

By the *decorations* are meant the ornamental shading and filling up of the letters. Thus letters may be represented as if made of wood, stone, or iron; and of pieces having square or polygonal section. They may appear as if seen obliquely, or as draped, vine clad, or casting shadows.

In spacing letters, it is a good rule to allow equal areas of blank paper between them.

Summing up; the preceding, and other particulars concerning letters, are systematically presented in the following table:—

LETTERS ARE
- GEOMETRICAL, whose *elements* are in their
  - Nature - - -
    - Straight, including polygonal letters, as S.
    - Curved.
  - Combination-
    - Simple - - - - - -
      - Rectangular, as - -H.
      - Oblique, as - - - -V.
      - Curved, as - - - -S.
    - Mixed, embracing - -
      - Rectangular and Oblique, as - - - - N.
      - Rectangular and Curved, as - - - - P.
  - Importance - -
    - Essential, as in A.
    - Complementary, as in A.
  - Relative size-
    - Equal - - - - - -
      - In single lines, as E
      - In double lines, as - - - - - - E.
        - Narrow, elements in single lines, as - - E.
        - Narrow, elements in double lines, as - F.
    - Unequal - - - - -
      - Essential elements widest, as in - -A.
      - Complementary elements widest, as in E. (Italian type.)
  - Finish. - - -
    - Plain.
    - Decorated (geometrically.)
- FREE, as German Text, Rustic, etc., Letters decorated with free ornaments.

It follows from this, that there cannot be very many radically different forms of letters; therefore, before proceeding to a further subdivision of geometrical letters, some of the ways may be mentioned in which *varieties* of letters are produced by modifications of the elements just given.

1°. By altering the proportions of height and width, forming *expanded* or *condensed* letters.

2°. By retaining or omitting the complementary additions.

3°. By making the wide columns of the letter massive or slender.

4°. By making the letters as if they were flat plates, or as if they were solid, or "block" letters.

5°. By representing the latter as seen directly, or obliquely, so as to show both face and thickness.

6°. By minor modifications in the outlines, as by rounding the caps into the columns.

7°. By making the usually curved letters polygonal.

8°. Varieties, without limit, may be made, by changes in the quantity and character of the decorations.

PRACTICAL REMARKS.

(*a.*) The thickness of the caps is the same as that of the narrow essential elements.

(*b.*) In pencilling letters, never pencil the ornaments, unless the letters are of extraordinary size, but pencil the outlines only, in very fine lines.

(*c.*) It is better to do all the pencilling by hand, since instruments would perpetually be hiding portions of the letters, and so preventing the eye from judging readily of their proper proportions.

(*d.*) Very small capitals and small letters are better put in off hand, in ink, between parallel pencil lines, to keep them of a uniform height.

(*e.*) The fifth row of Pl. II. shows a simple free-hand or "rustic" letter, in two sizes and styles. These are *bark* letters. Log letters are often seen in handbills, etc.

(*f.*) The sixth row embraces "skeleton" and "full faced" "small" Roman letters and italics. A common error consists in making the stems of the *b's*, *p's*, etc., too long. The total height of such letters need not be more than one and a half times the height of their bodies.

(*g.*) To avoid making letters slightly leaning, stand directly in front of the work, and with the eyes far enough from the paper to be able to see the position of the border of the plate, as a guide.

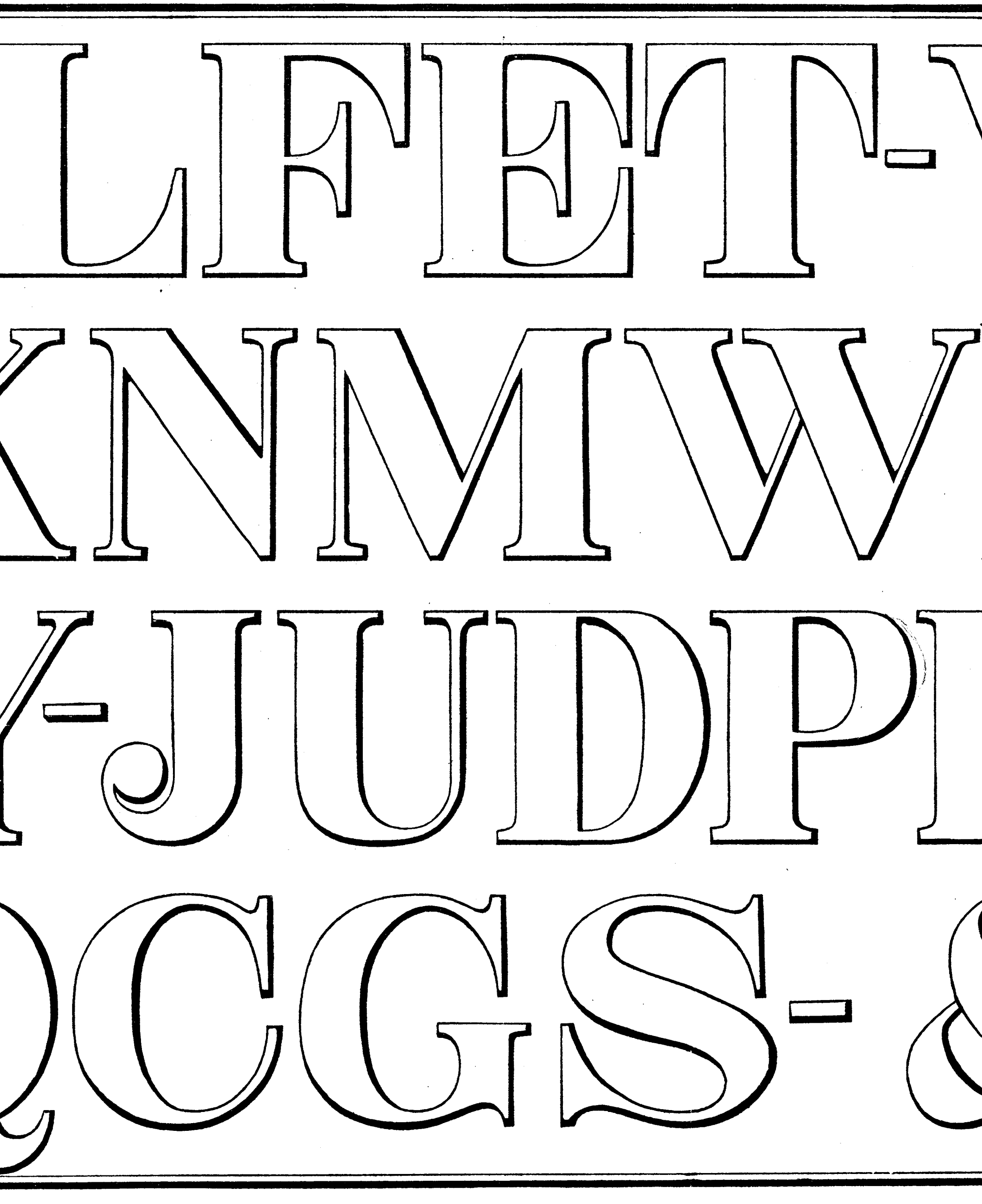
(*h.*) Curves can be more neatly sketched in by a dotting, or very light motion of the pencil, than by a continuous motion with firm pressure.

(*i.*) The ends of the arms of letters like G, C, S, etc., should not be far apart, vertically, but should come nearly together, and should be tangent to vertical lines, in order to give them a plump, finished, square, and stable look.

(*j.*) Even in the most fanciful letters, there is a certain appreciable consistency and orderly form. This results from their having an imaginary central skeleton of regular single lines, about which the outlines of their parts are equally balanced.

(*k.*) Pl. II. illustrates most of the distinctions of form mentioned in the preceding table, except the inelegant and unused Italian type. This plate, or one of similar nature, should be constructed by the student.

(*l.*) Polygonal letters may be substituted for curved ones by any who are particularly deficient in free-hand sketching. They may thus be able to secure a desirable uniformity of excellence in their work; though it is probable that the pains necessary to form an elegant polygonal letter, would secure an equally elegant curved one.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QRSTU VWXYZ

hijkl mnopqrstuvwxyz *abcdefghij*

CHAPTER IX.

GEOMETRIC SYMBOLISM.

Definitions.

A *symbol* is anything apparent to *sense*, which yet, of itself, *naturally* expresses, represents, or suggests to the mind some truth of *life*.

In this, a symbol is quite different from an emblem, or a type, as may be sufficiently seen by reflection on the universal use of the words. Thus every one says "the national *emblem*," speaking of his country's flag, but not the national symbol. Here, the connection between the *thing* and the *thought* is dependent on association, and may be equally strong, whatever the thing chosen may be; but it does not depend on any inherent relation of the thing to the thought, being established in the act of choosing the emblem.

A *type* belongs to the same general form of existence as the thing typified. It is a part, taken as a representative of the whole; a specimen, as the representative of a class; a lower form, as a representative of a higher form of being or action of the same kind.

To illustrate: The mingled verdure and bloom of spring, are *symbols* of the freshness, modesty and promise of unperverted youth. The tints and fruits of autumn, or a sunset in crimson and gold, are *symbols* of the close of a worthy, or a splendid career.

A monument is an *emblem* of departed greatness. A *broken* monument is a *symbol* of a broken life. The American flag is an *emblem* of the nation's life. Its rivers are the *symbol* of the *scale of its life*, its ideas, and its actions. Its best, and its worst, treatment of the Indians, are *types* of its highest and of its lowest humanity seen in all other relations of life.

Other illustrations. Water, by its properties, is a *type* of fluids generally. The ocean is of itself a *symbol* of eternity. A ring placed upon the finger becomes, by the manner of the act, an *emblem* of whatever put it there.

The oak, with its mighty and horizontal arms, is a *symbol* of all sufficient rugged strength. The elm is a *symbol* of united strength and grace, of cultured rather than native qualities. Hence the avenues of cities are lined with elms, rather than with oaks.

With the *idea* of symbols thus awakened, the following examples of geometric symbols will suffice to lead the mind into action upon the subject.

GEOMETRIC ILLUSTRATIONS.

A straight line is the symbol of repose, monotony, and death. It is so by reason of its monotony of form, in having but one unchanging direction. It is therefore adapted to situations where repose in the shape of fixedness or permanence is natural or desirable.

Thus, in the fervent tropical heats of a land like Egypt, where vigorous activity is to be dreaded, and the repose of utter inaction courted, the main outlines of the buildings, naturally and forcibly express these facts by the free use of straight lines, and *these*, as the boundaries of most massive and heavily proportioned forms. Massive short vertical columns, mile-long avenues of bolt upright figures, with folded arms and all facing alike, and the immense horizontal bases of the pyramids, and the lines of their immense stones, all illustrate this.

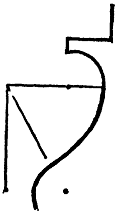
Also, in foundations generally, where permanence is most desirable, the main lines are mostly straight and horizontal.

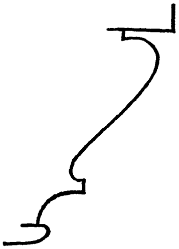
But in a church, the multitudinous flowing lines *should* only express the endlessly varied, yet only beautiful, individual and concerted life, that should, visibly, centre in, and flow from the stirring exercises and activities within it.

The circle is a symbol of monotonous routine, and hence, as a symbol of eternity, represents only a dormant, unprogressive one. It is thus, by reason of its single centre and uniform distance from that to the circumference, and its consequent uniform rate of variation of direction at all points, and its perpetual return to the same point of beginning.

Hence it was peculiarly appropriate that the Egyptians, whose earthly life was so largely expressed by the stiff, dead straightness of a right line, should have adopted the circle as their symbol of eternity, an eternity of endless dull repetitions of *one unvarying round.* "One unvarying round" is just what the circle sensibly is, and it is therefore the natural symbol of a life made up of routine in one unvarying round.

Again, life is either sensual or spiritual; and, in a given amount of it, as the one prevails, the other is wanting. Now monotony of life indicates absence of thought-activity, and hence, secondarily, the circle as the symbol of monotonous routine, unenlivened by varied thought, is also a symbol of sensuous, more than of intellectual existence. Hence the Romans, who were a grosser, and more materialistic people than the Greeks, made great use of the circle in their architecture, while the Greeks rejected it.





Thus the coarseness of the compound circular moulding is apparent in contrast with that of the freely varied curve of the second figure,* whose infancy quickly turns at maturity into a prolonged career of elegance, gracefully and quickly brought to a close, when its work is done.

The *ellipse* being only the general form, of which the circle is a particular case, it is not expressive of anything radically different from what is symbolized by the circle. Its continually varying rate of curvature expresses more of varied life than the circle does. Also its two foci, representing a two-fold governing purpose, or idea, or all engaging pursuit, give more of life to it as a symbol.

As contrasted with a circle, for a window, its compression in one direction may make it expressive of partly constrained or contracted, rather than of full-orbed and *equally* all-embracing life and character. Hence elliptical topped windows are less pleasing than semi-circular topped ones.

Quite otherwise from the foregoing is it with the *hyperbola,* which is sufficiently defined for present purposes by saying that it consists of two equal, opposite, and infinite branches, AF and BG, to which a pair of lines, M and N, crossing at the centre C, are tangent only at an infinite distance. Such lines are called *asymptotes.* The fixed points H and K are called its *foci*, each one, a *focus.*

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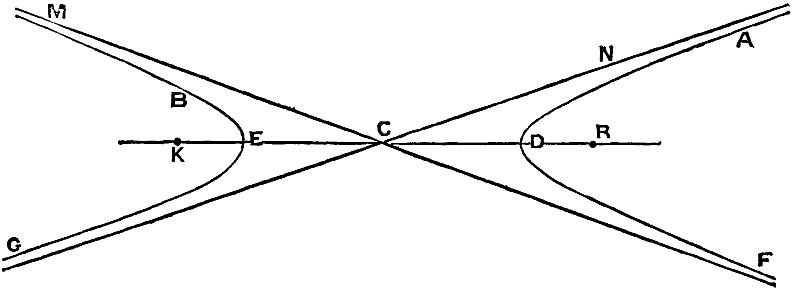
* "Greek lines," Atlantic Monthly, June and July, 1861.



The complete symbolism of this line is remarkable for its ready and striking truthfulness.

The general idea of the infinite approach of a curve to a straight tangent, as a symbol of an infinite progress towards perfection, or the absolute ideal, never actually attained, has long been familiar; but is realized in the case of *any* of the many very different curves which have asymptotes. But the complete symbolism of the hyperbola has perhaps never been defined.

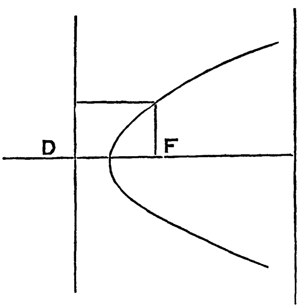
First, and for this world only, as proper to be mentioned here, there is *material* civilization, and there is moral or *spiritual* civilization. Also there is *material* barbarism and there is *moral* barbarism. There is the material civilization of Paris, and Berlin and London, and there is the moral civilization of the Quaker, and the philanthropist of New England, and of the little mountain democracies of Switzerland.

There is the *material* barbarism of the savage, and the hideous, appalling and exasperating *moral* barbarism of the hordes who are only all the more savage in nature, as they are more acquainted with arts and opportunities, which they pervert to savage uses, and who, as such, have blotted the annals of the world; as in the early chapters of the history of European enterprises, particularly in South America, Africa, and Asia.

Then, in the hyperbola, asymptote M may represent *material* civilization or perfection, or *material* barbarism either individual or social, and in opposite directions, as right and left, respectively, from C. Asymptote N may likewise represent the ideal of *moral* civilization, or of *moral* barbarism. Then, as each branch of the curve is divided symmetrically by the line or axis ED, if DA and DF, tangent to N and M at infinite distance from D, represent infinite progress towards the perfect moral and material ideals, respectively, then EB and EG, tangent in like manner to the same lines, may represent unlimited progress in material and moral evil, degradation and the bad.

Thus we have the crowning antithesis of the *good* and the *bad*, both *material* and *moral*, with unlimited possible progress towards each destiny, and in each form; all, expressed by the hyperbola, without obscurity, or confusing admixture with other considerations.

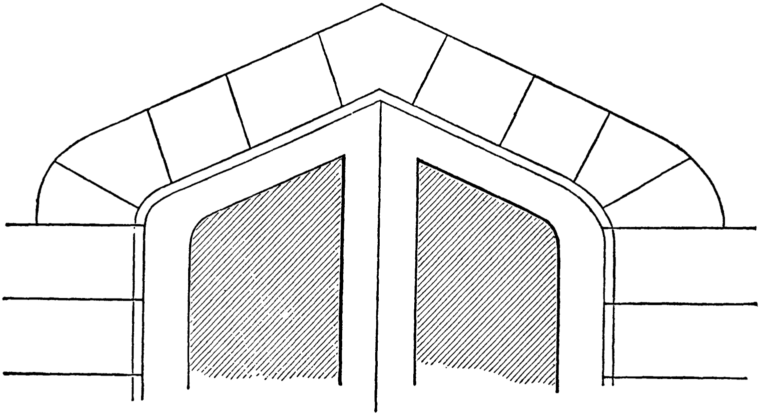
The *parabola*, each of whose points is equidistant from a fixed point, F, the focus, and a fixed line, D, the directrix, has but one branch, and no asymptotes. Whatever symbolism it may have, independent of the hyperbola, may not be yet apparent. Compared with that, its single branch may signify a career only good, and both material and spiritual as before, since it has bilateral symmetry about the axis DF.



The absence of the asymptote is expressive as showing that, being perfect in itself, it needs no outer standard to which to approximate; or conform itself, but is only perfect, though free.

As having a governing point *within itself*, while also conditioned by the line D, *which is infinite*, it is a symbol of the normal life of any perfect finite rational creatures; conditioned in their action by their *own* wills, and yet, in the final results of their action, by the will of the *infinite*.

This attractive image, from which the hateful thought of the *bad* is excluded, makes the gothic arch, formed of two opposite semi-parabolas, a beautifully appropriate entrance to any place where the ideal is to be sought, enjoyed, and if possible so realized; at least in thought and purpose, as to determine the progressive improvement of the life.



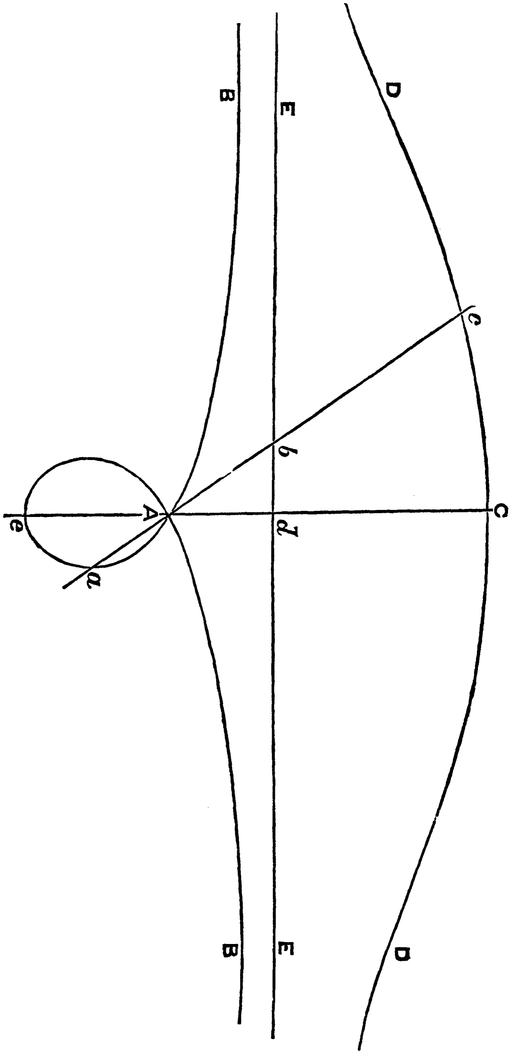
Spirals, are, as compared with the circle, noble symbols of immortal life, with growth and progress, inasmuch as, unlike the circle, they do not return into themselves, but ever proceed in wider and wider circuits, expressive of the expansive progress of all noble lives.

They may, therefore, well enter into the composition of the decorative parts, at least, or the seals, or heraldic devices of the buildings whose uses are representative of human progress. And they could hardly appear otherwise than in the ornamental details, because the visible representative of the inspiring idea should be, like the idea, itself, over and above the working rooms which must be merely adapted to the work to be done in them.

If, however, æsthetic thought in this department should ever lead to the general adoption of an educational symbolism, then buildings for the successive departments of any large institution might be arranged on a spiral, from the preparatory school to that in which resident graduates should remain to pursue special studies.

The *conchoid*, however, exceeds in ready and convenient expressiveness of grand fundamental ideas, any curve yet tried in the field of educational symbolism.

The *conchoid* is a curve of *two* parts, or branches, all of whose points are at the same fixed distance from a *given line*, measured on lines drawn from a *fixed point.* When this point is nearer the fixed line than the fixed distance, one branch of the curve will be looped. Thus E E is the fixed line, and A the fixed point. Then d C = $d\ e$; $b\ a = b\ c$, etc.



Now the primary ideas to be expressed in the organization of a comprehensive institution, are: 1°. A *Central Course of*

Study, from which various professional courses shall radiate; 2°. A personal directing body; 3°. A series of buildings devoted to the professional courses; 4°. A series of inferior buildings devoted to the lower purposes of organization; 5°. A select group of structures devoted to the most refined purposes of the institution. See now how perfectly the *conchoid*, when laid out on a grand scale on the ground, permits the *symbolical* expression of these ideas, in the *material* organization of an institution, as its published curriculum exhibits them in the printed expression of the *logical* organization.

1°. A grand building, surmounted with a dome, as the symbol of comprehensiveness, and with lofty porticos facing the four cardinal points of the compass, as the symbol of its equal openness to all, should stand at A, and contain instruction rooms for all the general courses.

2°. Professors, as the *personal* determining element in the life and work of an institution, should have residences ranged along the fixed determining line E E. And *d e* may be 1000 feet or more.

3°. D D, being the *superior branch* of the curve, should be allotted to the series of buildings devoted to the several professional schools, and reached from A by paths on the radial lines as *a b c*, which determine the points where they stand.

4°. B B, being the inferior branch of the curve, should be devoted to the gymnasium, janitor's lodge, bathing house, society (open) rooms, etc.

5°. The loop A *e*, as a separate and peculiar feature, should be set apart for an elegant garden enclosure, with fountains. etc., and faced by the observatory, chapel, and library buildings.

It may be added that, having regard to the beauty of a varied over a monotonous curve, like the circle, the superior branch of the conchoid would afford superior beauty as a reverse curve for the caps of doors or windows.

The *bilateral symmetry of the conchoid*, that is, the equality of the parts on each side of the line, C *e* admits another point of significance.

In a university, for example, such as some[*] believe in, of all embracing comprehensiveness, schools for the professions based immediately upon the *constitution of man*, viz., Theology, Law, Medicine, Politics, and higher Teaching, might be located on one side of C *e*, while those of the professions based on the *constitution of nature*, as adapted to subserve man, as Engineering, Architecture, Mining, etc., might be on the other side of C *e*.

Likewise the hyperbola, is a ready servant of educational symbolism, and perhaps even more perfectly, for the same purpose. For, besides placing the first, or "*humanistic*" class of professional schools on one branch of a hyperbolic avenue, laid out upon a suitable tract of ground, with its foundation *general* school at the focus, H, of that branch, and the second, or *technological* class of professional schools on the other branch, with *its* appropriate college of preliminary general culture at the focus K, a further subdivision is provided for. Each class of professions has its industrial, and its artistic subdivision; and the symmetry of each branch with respect to the axis, K H, permits the tangible expression of this subdivision. Thus, on the *humanistic* side, Schools of Theology, Law, Medicine, etc., could be on D A, and schools of Poetry, Oratory, and Vocal Music could be on D F.

Likewise, Schools of Industrial Technology, as of Engineering, Building, Mining, and Technical Chemistry, could be on E B, and schools of Architecture, Decorative Design, Instrumental Music, etc., could be on E G.

Finally, those disposed to contend for the equal rank and dignity of the two main classes, humanistic and technological, of professional pursuits, would adopt the hyperbola, to determine the arrangement of the assemblage of buildings composing the general *material* organization of the university. Those who should claim superior rank for the humanistic class, would employ the conchoid, and place the schools of that class on its *superior* branch; while those who would avoid all such rivalries, as well as the bewildering unwieldliness of so colossal an organization, would be likely to employ the conchoid as first explained, and for one class only of professions.

The *positions* of lines have a significance, as well as their forms. Thus a prevalence of *vertical* lines symbolizes aspiration, upward-tending thought and purpose; and hence gives noble meaning to a lofty gothic cathedral interior, where the prevailing direction of the lines is vertical.

The same idea gives effect to the humblest village spire.